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Production anisotropy of $h^{\pm}$, $\pi^{\pm}$ and $p/\bar{p}$ at high-p_{T} in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

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Abstract

The high-p_{T} particle production anisotropy in Pb–Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV studied by the ALICE experiment is presented. The event plane and the four-particle cumulant method are used to extract the v_2 and v_3 flow coefficients of unidentified charged hadrons, pions and protons out to p_{T}=20 GeV/c. The observed non-zero values of the elliptic flow in the high-p_{T} region where the collective phenomena are negligible are discussed.

Keywords: heavy ion collisions, flow, high-p_{T} particles, quark, gluon, proton, pion

1. Introduction

Although the jet quenching phenomena were extensively studied at RHIC [1, 2] the first data from LHC revealed many interesting surprises. The inclusive charged particle nuclear modification factor, R_{AA}, measured in central Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV shows, in contrast to RHIC [3], the rising trend [4, 5]. More direct studies of the fully reconstructed jet production in central Pb-Pb collisions show significant di-jet imbalance preserving, in the same time, similar back-to-back acoplanarity as in the pp data [6, 7, 8, 9]. Furthermore, the first glance at the fragmentation function modification in these studies shows surprisingly null results [10]. Despite the massive quenching the jet properties are apparently not altered by the medium. Although this observation seems to be in a relatively good agreement with models assuming the combination of elastic and inelastic parton energy loss where the fragments observed within the jet cone are produced outside of the medium [11, 12] the mechanism of the parton energy loss certainly deserves more detailed exploration. Another interesting observable which may provide more stringent constraints to the jet quenching models is the high-p_{T} particle emission anisotropy.

2. Anisotropic flow at high transverse momentum

The azimuthally anisotropic particle emission in Ultra Relativistic Heavy Ion collision is studied for more than 20 years and it is attributed the collective phenomena in the early phases of the collision evolution (e.g. [13, 14]). Whereas at low $p_{\mathrm{T}} \lesssim$ 2-3 GeV/c, the production anisotropy is qualitatively described by hydrodynamic model calculations [15], in the high transverse momentum region the different time scales of dense medium formation and high-p_{T} particle production precludes the collective phenomena to occur. The azimuthal anisotropy is then dictated by different

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thickness of the nuclear medium in different parton trajectory angles w.r.t. the reaction plane [16]. In both, low and high transverse momentum regions, there are more particles produced along the reaction plane angle. In the former case it is due to the larger pressure gradient and in the latter one it is due to the shorter path length experienced by high-p_T parton.

The ALICE Collaboration has recently published the measurement of the azimuthal anisotropy of identified charged pions and protons out to p_T=20 GeV/c [17]. The azimuthal anisotropy is characterized by the coefficients of the Fourier expansion of the particle azimuthal distribution with respect to the event plane:

$$v_n(p_T, \eta) = \langle \cos[n(\varphi - \Psi_n)] \rangle, \quad (1)$$

where p_T, η, and φ are the particles transverse momentum, pseudo-rapidity, and the azimuthal angle, respectively, and Ψ_n is the n-th harmonic symmetry plane angle. Due to the event-by-event fluctuations of the initial geometry the symmetry plane Ψ_n deviates from the reaction plane defined by the beam direction and the impact parameter. This gives rise to non-zero odd harmonic coefficients (see e.g. [18]). Results presented in this note are based on the analysis of charged particle tracks measured by the Time Projection Chamber (TPC) with pseudo-rapidity $|\eta| < 0.8$ and the full azimuthal acceptance. Two scintillator arrays (VZERO) of $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$ are used for the symmetry planes determination.

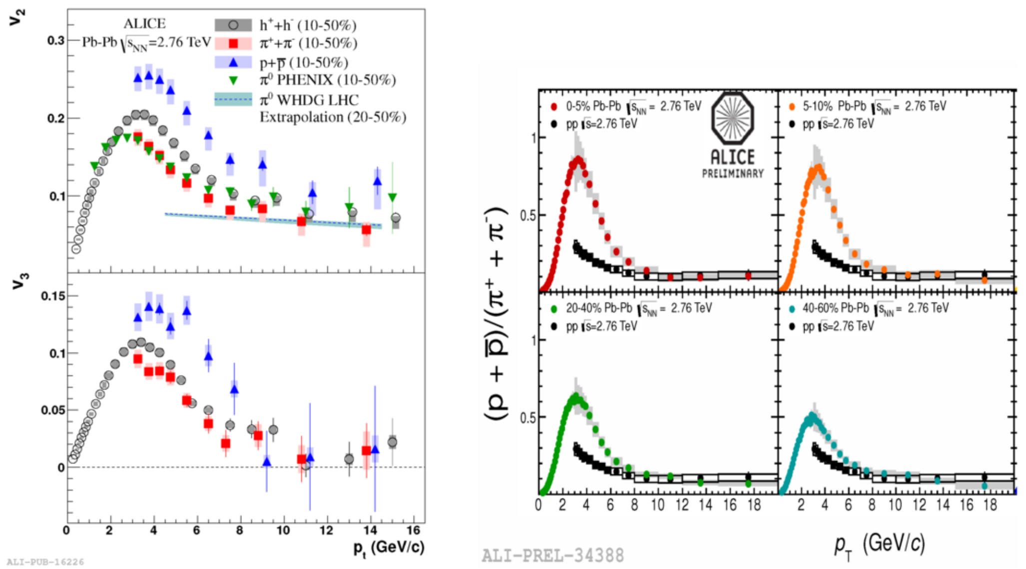

Figure 1: Left: Unidentified charged hadrons, pion and proton v_2 (top) and v_3 (bottom) as a function of p_T in the 10-50% centrality bin. PHENIX π^0 v_2 measurements are also shown [19]. The dashed line represents the WHDG model calculations for neutral pions [20] extrapolated to the LHC collision energy for the 20-50% centrality range. Error bars (shaded boxes) represent the statistical (systematic) uncertainties. Right: The ratio of the $(p + \bar{p})/(\pi^+ + \pi^-)$ yields in four centrality bins in Pb–Pb collisions (color online) and in pp (black solid circles).

The pions and protons identification is based on the measurement of the dE/dx in the TPC (for details see [21]). The flow coefficients v_n are measured using the event plane method (v_n{EP}) and the four-particle cumulant technique (v_n{4}) [22]. It is well known that these methods are sensitive, although in a different way, to the non-flow contamination induced by other sources of the particle correlations e.g. jet-fragmentation or resonance decays [14]. However, these non-flow correlations are, to the large extend, suppressed by a large pseudo-rapidity separation between the measurement of the event plane (VZERO) and the particle anisotropy (TPC). The residual non-flow contamination was estimated by a comparison of the azimuthal correlations measured in heavy-ion collisions to those in pp (details in [17]). The measured $v_{2,3}$ values for $h^{\pm}$, $\pi^{\pm}$ and $p/\bar{p}$ in the 10-50% centrality bin are shown on Fig. 1. The proton v_2 and v_3 are higher than that of pions out to $p_T\approx 8$ GeV/c where the uncertainties become large. This behavior is qualitatively consistent with a picture where particle production in this intermediate p_T region includes interaction of jet fragments with bulk matter [23].

It is worth to mention another possible interpretation of the fact that the proton v_2 is larger than the pion one. As discussed e.g. in [24], gluon interaction rate with the medium is 9/4 times larger (the ratio of the Casimir color factors) than the rate of the quark interaction and thus the medium could act as a "gluon filter ". This effect was mentioned also in [25] as one of the possible interpretation of the observed enhancement of near-side per-trigger associated conditional yield I_{AA}. When there is a larger fraction of gluon-production in the case of protons (see discussion below) as compared to pions then together with the larger gluon quenching it is natural to expect the proton $v_{2,\mathrm{proton}}$ to be larger than $v_{2,\mathrm{pion}}$. In this case, one could also expect that the ratio of the integrated yields $(p+\bar{p})/(\pi^+ + \pi^-)$ should fall below the value measured in pp collisions. However, as one can see from right panel of Fig. 1 where the ALICE measurement of $(p+\bar{p})/(\pi^+ + \pi^-)$ ratio is shown, there is no indication of such a proton yield suppression in the central Pb–Pb as compared to pp collisions.

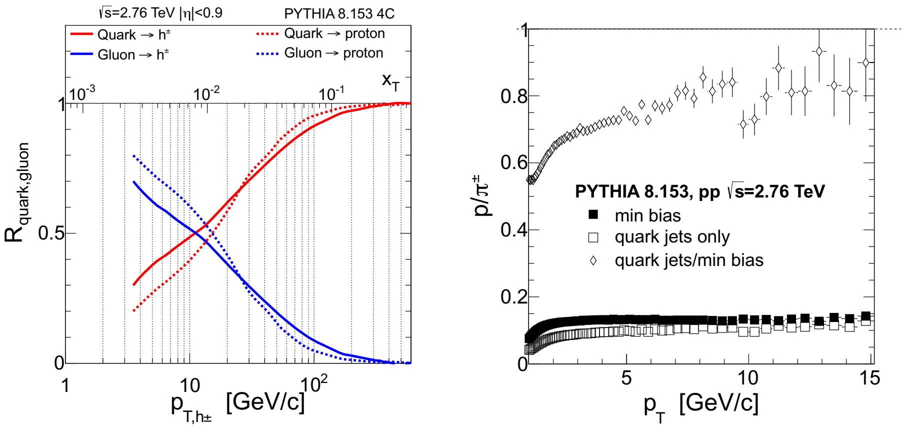

Figure 2: Left: Relative charged particle (solid lines) and proton production from quark and gluon jets (dashed lines) according to PYTHIA 8.153 pp $\sqrt{s}$=2.76 TeV with CTEQ 5L, LO parton densities [26]. Upper axis shows the relative momentum fraction $x_T = 2p_T/\sqrt{s}$. Right: The ratio of proton to charged pion yields from the minimum bias PYTHIA simulation (solid squares) and the same ratio from quark jets only (open squares). The double ratio of quark jet to minimum bias $p/\pi^{\pm}$ from the PYTHIA simulation is represented by open diamonds.

However, one may question the sensitivity of the $(p+\bar{p})/(\pi^+ + \pi^-)$ ratio to the possible gluon filtering phenomenon. In order to to answer this question we have studied the proton/pion production in PYTHIA 8.153 pp $\sqrt{s}$=2.76 TeV with CTEQ 5L, LO parton densities [26]. The left panel of Fig. 2 shows the relative charged particle (solid lines) and the proton production from quark and gluon jets (dashed lines). It is evident that in the Lund fragmentation model implemented in PYTHIA the proton production favors gluon jets to somewhat larger p_T (the cross point moves from $p_T\sim 10$ Gev/c in the case of $h^{\pm}$ up to $p_T\sim 15$ GeV/c for protons) than the light charged pions. The ratio of $p/\pi^{\pm}$ from the same PYTHIA simulation plotted as a function of transverse momentum in the minimum bias collisions (solid squares in the right panel of Fig. 2) reaches in the high-p_T region the asymptotic value of ~ 0.15. When the proton production only from quark jets is calculated (maximal gluon filtering) then the $p/\pi^{\pm}$ ratio is reduced (open squares). The double ratio of the minimum bias $p/\pi^{\pm}$ to this from quark jets is shown with open diamonds. The double ratio indicates that in the extreme case, when all gluon jets are fully suppressed, the $p/\pi^{\pm}$ drops by about 40% in the low-p_T region ($p_T< 3$ GeV/c) and the reduction is less than ~20% in the $p_T >10$ GeV/c. This PYTHIA based analysis, strongly suggest that $(p+\bar{p})/(\pi^+ + \pi^-)$ is largely insensitive to the gluon filtering in the high-p_T region where the baryon anomaly is negligible. The relative smallness of the $p/\pi^{\pm}$ reduction in the case of purely quark-jet proton production also indicates that $v_{2,\mathrm{proton}} > v_{2,\mathrm{pion}}$ is very unlikely influenced by the gluon filtering, although some small reduction of the relative gluon jet yield can not be excluded.

3. Summary

The flow coefficients of the azimuthal distribution of unidentified charged particles, pions and protons measured by the ALICE collaboration in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV over a broad range of transverse momentum are presented. The unidentified charge particle v_2 and v_3 coefficients are found to be positive even at high transverse momenta $p_T > 8$GeV/c. In contrast to "collective" origin of the momentum anisotropy at low-$p_T \lesssim 3$ GeV/c the finite values of v_2 for $p_T > 10$ GeV/c are likely to be due to the collisional and radiative energy loss of partons propagating through the nuclear medium in agreement with WHDG model calculations. The proton v_2 and v_3 are larger than those of charged pions. This observation seems to be in a good agreement with the picture where particle production in this intermediate p_T region includes interaction of jet fragments with bulk matter. The PYTHIA simulation was used to test to what degree the $v_{2,\text{proton}} > v_{2,\text{pion}}$ could be caused by a different interaction rate of gluons and quarks with the nuclear medium.

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